Impact of innovative land management practices on annual runoff and soil losses from 27 catchments of South-East Asia

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Abstract

Rapid changes of the upland farming systems in Southeast Asia mainly result from increased population pressure and dependence on 'market forces'. Current uncertainty on the amplitude of the impact of these changes on land degradation and environmental services weakens the message of the scientific community, facilitates controversies, and delays, consequently, the decision-making of authorities despite the necessary adoption of new socio-economic strategies. In particular, the links between agricultural activities in the upland and off-site effects are in question because of the difficulties to derive results from plots to larger scales. Recent workshops on the management strategies in the uplands of Southeast Asia underlined the need for long term catchment studies to provide valid data. The objectives of this paper that summarizes the main results obtained by this consortium over the last six years are to assess the impacts of i) rapid land use changes and possible climatic changes on annual run-off ratio (Rc) and sediment yield including bed load (BL) and suspended sediments loads (SL) from 27 catchments and sub-catchments of five countries in South-East Asia (Indonesia, Laos, Philippines, Thailand, Vietnam), ii) various soil conservation practices tested in these catchments. Topography, soils and initial land use were surveyed in each catchment. Monitoring included climatic, hydrologic and erosion (bedload and suspended load) data, land use and crop yields, farmers income. In additions, innovative practices, either spontaneous or programme-induced, were tested : Tree plantations, improved fallow with legumes, agroforestry practices (native grasses strips and some agroforestry crops as hedgerows), direct sowing and mulch-based conservation and fodder crops. Stepwise regressions analyses were performed to identify the best predictors for runoff, bedload and suspended load. Data clearly demonstrate that annual crops, especially maize and cassava, without conservation practices, promote soil erosion at the catchment scale. Annual crops in upland catchment have therefore an off-site impact on water quality. They epitomize the positive role of conservation technologies in reducing runoff and suspended load. Despite their efficiency in combating soil erosion, only few conservation techniques are adopted on the long term especially by tenant farmers. Our data suggest that soil erosion tends to increase with population density and more surprisingly with income per capita. If no incentives reward upland communities that adopt appropriate land use management systems, it is most likely that land degradation will increase in the next few decades with off-site consequences for more urban and industrialized lowland communities.

1. Introduction

In Southeast Asia, the decline in productivity of lowlands lead to continued expansion of cultivated land area on increasingly steep-slopes often involving the clearance of native vegetation in the uplands. Being an open access resource, the upland soils have been subjected to misuse and unsustainable farming practices, resulting to degradation. Land degradation is often associated with poverty (e.g., Pender et al. 2001, Penning de Vries et al. 2002) especially in the mountainous regions dominated by people who are often politically disempowered and economically marginalized. Public interest in these communities emerged mainly from a realization that environmental degradation of uplands affects the richer communities (e.g., Lian 1993): run-off and soil loss resulting from the changes in land use and/or climatic conditions concerns not only the upland farmers but also the users of water resources downstream. Peculiar attention has thus to be paid in the region to upper catchments since it is generally hypothesized that increased exploitation of land resources in small headwater catchment areas (usually <1 km2) with associated fragmentation of native forest vegetation results in increased sediment discharge and elevated nutrient loads that act to reduce water quality and availability to downstream users (eg., Bruijnzeel 2004). As the land resource base becomes less productive, food security is compromised and competition for dwindling resources increases, favouring potential conflicts. Thus a downward eco-social spiral is created when uplands are eroded and nutrient depleted by unsustainable land management practices resulting in lost soil stability leading to permanent damage. However, this spiral should not be regarded as a fatality. As mentioned by Scherr (2000), it is both avoidable and reversible in many circumstances hence the effort of most management agencies and donors to support new appropriate technologies.

Current uncertainty on the amplitude of global changes weakens the message of the scientific community, facilitates controversies, and delays, consequently, the decision-making of authorities despite the necessary adoption of new socio-economic strategies. This urgency to gain reliable predictions, together with estimates of uncertainty, is particularly sensitive in Southeast Asia, the most populated area of the world and with a very fast rate of economic growth. Invariably the entire region will be impacted by the insatiable consumptive footprint of the emerging economies of China and India. As the pace of economic and social change in this region accelerates, the possibilities of discontinuous and accelerated change cannot be ignored. This would require converting large tracts of current rainforests to agricultural land with potentially critical environmental implications. In this respect these changes could take the form of natural disasters (e.g. floods) and crop failure (e.g. due to drought), especially in the context of a climatic change. Bruijnzeel, (2004) reported that rainfall in the whole of Thailand shows a remarkable decreasing trend since the 1950s during the month of September, i.e. when the southwest monsoon current is weakening. In July and August, when the monsoon is still strong, no such decrease is noted (Yasunari 2002). In East China, the aridity index tends also to increase (Fu 2002) as a result of changes in surface roughness, leaf area index and reflection coefficient. Thus, the observational evidence concurs with model predictions in suggesting that large-scale land-cover change in East Asia is indeed capable of producing changes in the regional surface climate (Fu 2002). Where annual rainfall is known to have decreased significantly over the last decades (Sahel, Western Australia), no concurrent decrease has been observed in the frequency of extreme events (see review in Valentin 2004). Under these conditions, no decrease in the frequency of flooding is to be expected from a reduction of mean annual rainfall and IPCC (2001) predicted of increased runoff of 50-150% in Southeast Asia. Public concern is growing as illustrated in the inflating frequency of newspaper articles ('Bangkok Post') both on increased flood frequency and the impact of drought (Planchon, oral communication). Studies of erosion under climate change have not taken into account farmer choices of crop rotations or planting dates, which will adjust to compensate for climate change. Adaptation of the upper catchments in Southeast Asia to climate and land use changes is dependent on their current and predictable adaptive capacity. The assessment of their vulnerability to these changes and their adaptation should be a priority, especially in the developing countries where investments are usually more focused on recovery from a disaster than on the creation of adaptive capacity (Mirza 2003).

The interactions between climatic and anthropic changes remain much less studied in this region than in the areas of mean latitude, although their effects are likely to have impacts at the global level. Integrated and cross-scale knowledge is therefore essential to understand current processes and predict the future trends. A key element in achieving these goals is the ability to operate at multi-scales within a catchment where the integration of attributes will enable integrated approaches. Also essential is the need to quantify the sensitivity and resilience of fragmented landscapes in upper catchments. Recent workshops on the management strategies in the uplands of Southeast Asia underlined the need for long term catchment studies (Tomich et al. 2004; Sidle et al., 2006ab). Because land degradation results from a web of spatial and time dependent processes, the question has been raised whether the researchers are really on track to provide useful scientific inputs for developing and testing promising new environmental policy interventions (Tomich et al. 2004). More and more scientists consider that the impact of deforestation on large scale flooding has been overestimated (Kiersch and Tognetti, 2002; Bruijnzeel et al., 2004) and that major sources of sediments can be roads, poorly constructed and maintained terraces, coffee plantations , bank erosion (Sidle et al., 2006b).

In order to provide sound data on the extent of accelerated soil erosion resulting from rapid land use changes at the appropriate scale, it was decided by the end of the 90's to launch a regional network 'the Management of Soil Erosion Consortium' associating five countries (Indonesia, Laos, Philippines, Thailand and Vietnam), an International (IWMI) and a French (IRD) institutes and to implement a long term research programme to monitor at the catchment scale changes in the farming systems, runoff and sediment yields and to test various improved practices to reduce soil losses and enhance livelihood of the communities (Maglinao et al., 2004). The objectives of this paper that summarizes the main results obtained by this consortium over the last six years are to assess the impacts of i) rapid land use changes and possible climatic changes on annual run-off ratio (Rc) and sediment yield including bed load (BL) and suspended sediments loads (SL) from 27 catchments and sub-catchments of five countries in South-East Asia (Indonesia, Laos, Philippines, Thailand, Vietnam), ii) various soil conservation practices tested in these catchments. These objectives meet the two technology transfer needs related to catchment processes recently identified for the tropics of Southeast Asia (Sidle et al. 2006a): i) 'how to incorporate the appropriate level of 'good science' with socio-economic issues and constraints, ii) develop appropriate management perspectives.

2. Materials and methods

Benchmark catchments

Selecting the benchmark catchments for the study involved the participation of the local stakeholders, the farm situation and the willingness of the farmers in the area to participate, the representativity of the catchments, and the accessibility of the catchment for monitoring the project activities. Other considerations included the presence of other related projects that would complement the project (for Philippines), the institutional links associated with the selected site (for Indonesia). These 27 catchments and sub-catchments have been selected and monitored since 2000. Table 1 shows the basic biophysic information of the benchmark sites. Their size vary between 0.6 and 285 ha, mean slope steepness between 8% and 48%, annual rainfall between 1028 and 3840 mm.

Table 1. Main attributes of the selected catchments

Country	Indonesia	Laos	Philippines	Thailand	Vietnam
Catchment name	Kalisidi	Huay Pano	Mapawa	Huay Yai	Dong Cao
Province	Semarang	Luang Prabang	Bukidnon	Phrae	Hoa Binh
Latitude	$07^0$20'S	$19^0$51'10''N	$08^0$02'50''N	$18^0$13'20''N	$20^0$57'40''N
Longitude	110^0E	$102^0$10'45''E	$125^0$56'35''E	$100^0$23'40''E	$105^0$29'10''E
Elevation (m)	390-510	400-700	1080-1505	400-480	125-700
Mean Slope (%)	30-46	18-61	18-26	8-15	28-38
Geology and landform	Basaltic lava	Shale; schist	Basalt, pyroclastics	Siltstone, sandstone	Schist
Rainfall* (mm)	1,208-3,840	1,305-1,414	347-548	1,028-1,493	1,048-2,368
Number of years§	3 (2001-2004)	5 (2001-2005)	3 (2000-2002)	5 (2001-2005)	5 (2001-2005)
Soils	Inceptisol	Ultisol; Entisol	Ultisol, Inceptisol	Alfisol; Ultisol	Ultisol
Vegetation and land use	Rice, maize, rambutan	Forest, bush fallow; upland rice, corn, job's tears	Forest plantation, open grassland, maize, potato	Soybean, mung bean, corn, tamarind	Cassava, tree plantations
Tested practices	Fodder	Improved fallows	natural vegetative strips	None	Fodder
Hydrology	Permanent flow	Permanent flow	Intermittent flow	Intermittent flow	Permanent flow
Number of equipped catchments	4	8	5	5	5
Catchment size (ha)	1.1 - 285	0.6-59.3	0.9-84.5	3-93	2.6-49.7

* over the periods of hydrological measurements (only few months per year in some sites)

§ data are not yet available for 2006

Fig.1 depicts for each selected site the evolution of two main drivers of land use change: market access, as reflected by the annual income per capita, and population density. The selected sites in Laos, Vietnam and Philippines are located along a similar and balanced demographic and economic 'trajectory', which suggests that population increase does not lead invariably to a decreased annual income. Cramb (2005) recently hypothesised that fertility management technique for acid upland soils was influenced by these two drivers. Fig. 1 tends to confirm this hypothesis: in Laos, at low population densities and with low income, farmers rely on shifting cultivation to extract a subsistence income from upland soils. The fallow period has been recently reduced from 8 to 2 years (de Rouw et al., 2005) as a consequence of a rapidly increasing population pressure resulting from natural growth but also resettlement and conservation national policies (Lestrelin and Giordano, in press). A greater number of tillage operations promotes tillage erosion on steep slopes (Dupin et al. 2002). In Vietnam and the Philippines, farmers use rather low inputs of both organic and inorganic fertilizers. The contrasted socio-economic conditions favour the intensive use of industrial agricultural inputs in Thailand, and organic inputs in Indonesia.

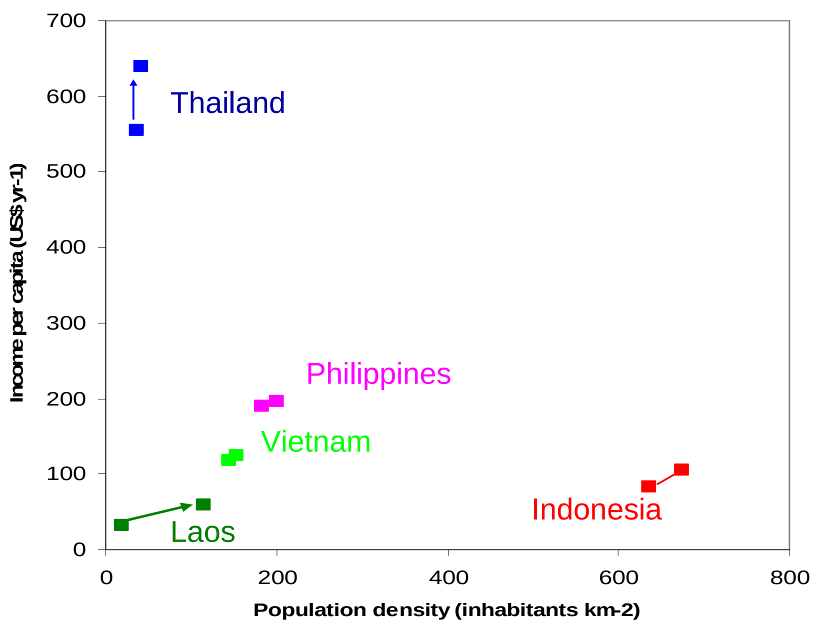

Fig. 1 Density and income per capita in the five country sites. The two dots per country correspond to the recent past and current situations.

Surveys and monitoring

Topography, soils and initial land use were surveyed in each catchment on the onset of the experiments using a GPS and a theodolite. This georeferenced data were used to establish a GIS for each catchment. Monitoring included:

- Climatic data: automatic weather stations and several manual rainfall gauges over each catchment,
- Hydrologic data: from 4 to 8 hydrologic stations equipped with automatic water level recorders;
- Erosion data: suspended load was assessed using automatic water samplers at time intervals from 2 minutes to 1 hour depending on water discharge peaks ; bed load sediments, i.e., the sediments trapped in the weirs were collected and weighed after each main rainfall event or in some countries, or only once at the end of the rainy season. In Thailand sediments core were collected from the reservoir downstream of the benchmark catchment.
- Land use: a map based on field surveys was prepared every year.
- Productions: in most cases, crop yields were measured in the field.
- Farmers' income: socio-economic surveys were conducted at least in the beginning and at the end of the experiments.

Innovative practices

One aspect of addressing the adverse impacts of soil erosion is the identification of innovative practices that would address both natural resources conservation and at the same time provide livelihood opportunities to the farmers in the catchment. Identification of innovative practices for the MSEC catchments involved the conduct of interdisciplinary participatory approach. Prior to the stakeholders' meetings, the researchers have already studied the biophysical, social and economic conditions the catchment, which should be considered in identifying the interventions. The list of interventions that have been developed and proven effective in previous studies were also gathered by the researchers to facilitate the discussion with the farmers. The land management options were identified and introduced through farmer consultations. With the farmers' participation in the selection process, it is expected that they will continue practising the system, which in the long run will provide better income and less resource degradation. The introduced land management options are evaluated for their acceptability and sustainability, and a wider uptake at the community level is promoted to produce greater impact. Main innovative practices included:

- Tree plantations (*Acacia mangium, Styrax*) in Vietnam.
- Improved fallow with legumes (*Cajanus cajan and Crotalaria micans)* in Laos.

- Agroforestry practices: native grasses strips and some agroforestry crops as hedgerows in the Philippines.
- Direct sowing and mulch-based conservation agriculture *(*with *Brachiaria ruziziensis)* in Laos.
- Fodder crop: ruzi grass (*Brachiaria ruziziensis)* in Vietnam and Benggala grass (*Panicum maximum*) in Indonesia.

Statistical analyses

Statistics for the erosion variables of runoff coefficient (Rc), bedload (BLD) and suspended load (SUL) were computed from the 95, 104 and 79 catchment-years available, respectively. Linear regression analyses were performed with a personal computer version of the SPSS® package using stepwise linear regression. This analysis allowed independent variables to be individually added from the model at each step of the regression, and therefore evaluation of the changes in the R-squared value. In the linear regressions, only parameters statistically significant at the 0.01 level were retained. These stepwise regressions were used to identify the best predictors for runoff coefficient and sediment yield.

3. Main results

Impact of land use changes and innovative strategies on soil erosion

In Laos, the upland rice cultivation produced 5.7 ton ha^{-1} yr^{-1} and fallow 0.4 ton ha^{-1} yr^{-1}. In other words, in the prevailing system till the 90's (1 year of cultivation, 8 years of fallow), the mean annual sediment yield was 0.9 ton ha^{-1} yr^{-1}. Because this system tends to include 2 years of cultivation and only 2 years of fallow, mean annual sediment yield increases to 3.1 ton ha^{-1} yr^{-1}. Because of growing difficulties to control weeds, upland rice is gradually replaced by maize that produces nearly the double of sediment than upland rice (11.3 ton ha^{-1} yr^{-1}). With the increased cultivation period (2 years), the reduction of the fallow period (2 years) and the replacement of upland rice by maize, the mean annual sediment yield (5.9 ton ha^{-1} yr^{-1}) tend to increase by nearly 600%. By contrast, improved fallow produces only 0.1 ton ha^{-1} yr^{-1} of sediments, and continuous direct sowing and mulch-based conservation agriculture 0.7 ton ha^{-1} yr^{-1}. Economic and technical constraints (use of herbicides) limit currently the adoption of the direct sowing system but the improved fallows systems seem to have more chance to be adopted by farmers.

In the Vietnamese MSEC catchment, the predominant land-use has gradually changed from cassava to trees plantation from 2000. Some farmers had the opportunity to sell their land whilst others under a policy directive planted trees or have practiced improved fallows. There has been a dramatic change in the extent of cassava production in the catchment with the total area declining from 40% of the watershed area in 2001 to less than 0.5% in 2004. With this decline in area under crops, the opportunity has arisen to introduce a livestock component into the catchment. The impact of the fodder species (*Brachiaria ruziziensis*) established under a no till regime has been evaluated with respect to its ability to reduce erosion from these slopes. The annual soil loss recorded through bed load measurements have decreased from 7.3 ton $ha^{-1}.yr^{-1}$ with cassava to 1.0 ton $ha^{-1}.yr^{-1}$ with the establishment of fodder and 0.7 ton $ha^{-1}.yr^{-1}$ with tree plantation.

In the Philippines, the traditional mechanised up and down cultivation of maize is highly erosive (36.2 ton $ha^{-1}.yr^{-1}$ of bedload). Cultivated on the contour with vegetative grass strips, maize produces only 0.7 ton ha-1.yr-1, which is similar to the bedload from grass.

In Indonesia, 25% of the land under the Rambutan plantation were converted into cassava. This condition creates an increase in total sediment yield yields from 2.9 to 13.1 ton $ha^{-1}.yr^{-1}$with dominantly suspended load. A lower bed load after encroachment, compared to that before encroachment, is assumed to be due to tillage method, where farmer makes dikes for cassava along contour line in the lower slope. This encroachment resulted from the need of the farmers to cultivate more land for their seasonal or annual crop farming to increase their income. The introduction of the fodder grass as an option to reduce erosion and improve farmers' income through livestock integration resulted in a significant reduction in the sediment yield (from 10.8 to 2.7 ton $ha^{-1}yr^{-1}$). This could be attributed to. It should be noted that in 2002, more than 60% of the area adopted this intervention.

In Thailand, because of fungi on mungbean and higher price for maize, the soybean-mungbean was replaced by maize since 2004. Abandoned land, secondary forest patches and even orchards of sweet tamarind trees were cultivated in maize. The sediment yields, already high with soybean-mungbean (4.9 ton $ha^{-1}yr^{-1}$), even under fruit trees (3.0 ton $ha^{-1}yr^{-1}$), were more than doubled by these land use changes (11.7 ton $ha^{-1}yr^{-1}$).

Impact of an exceptional rainfall event

In Thailand, during the rainfall event of 16 and 17 June 2004, it fell 218.2 mm in 6 hours with a maximum intensity of 70mm h^{-1}, an event with a return period of 100 years. Concentrations of 35 g l^{-1} of suspended sediments were measured in the main weir. The annual year sediment yields in the main wear (17 ton $ha^{-1}yr^{-1}$) were nearly 20 times higher than for the three previous year (mean: 0.9 ton $ha^{-1}yr^{-1}$). This proportion was smaller in the four sub-catchments (from 2 to 10) suggesting that stream bank erosion was the major process. Sediment cores sampled from the downstream reservoir the catchment (121 km²) of which is mainly under forest show that the sediments of 2004 were as thick as the total sediments of the four previous years (S. Huon, person. com.)

Main predictors of runoff and sediment yield

Runoff coefficient, Rc, the ratio (in %) between runoff and rainfall, bedload (BLD; ton $ha^{-1}yr^{-1}$), suspended load (SUL; ton $ha^{-1}yr^{-1}$) and sediment yield (TSY, ton $ha^{-1}yr^{-1}$c with TSY=BLD+SUL) can be statistically predicted by the following equations presented in Table 2:

Table 2. Statistical predicting equations of runoff and sediment yield.

Rc, the ratio (in %) between runoff and rainfall, bedload (BLD; ton $ha^{-1}yr^{-1}$), suspended load (SUL; ton $ha^{-1}yr^{-1}$) and sediment yield (TSY, ton $ha^{-1}yr^{-1}$c with TSY=BLD+SUL). Cp: the percentage area (%) of the catchment with conservation practices in the catchment with conservation practices (improved fallow, direct sowing, grass strips and natural vegetative strips, terraces with grass risers). CP alone explains 34% of the variance of Rc. Mz: total area cultivated in maize (%). Δz: difference of elevation from the top of the catchment to its outlet (m). Sa: sand content in the top soil (%). Eu: area planted in Eucalyptus. Mz_2: area cultivated up and down in maize, two cycles a year (%). Mz_1: area cultivated in maize, one cycle per year (%). Ca: total area cultivated in cassava (%).

Variable	Equation	Eq. #	n	R^2
Rc	$Rc = 4.87 - 0.32\ Cp + 0.24\ Mz + 0.01\ \Delta z + 0.38\ Sa - 0.51\ Eu$	1	95	0.59
BLD	$BLD = 0.181 + 0.596 Mz_2 + 0.114\ Mz_1 + .104\ Ca$	2	104	0.79
SUL	$SUL = 1.842 + 0.208\ Ca + 0.038\ Mz - 0.030\ Cp$	3	79	0.25
TSY	$TSY = 3.265 + 0.109\ Mz$	4	79	0.22

4. Discussion

A surprising result from the statistical analyses is that topographic, soil factors and catchment morphometric factors (area, perimeter, …) were not among the most important predictor of runoff and sediment yield. The only two factors selected by the stepwise regressions have some impact on runoff but not on soil erosion. They were Δz, the difference of elevation, which may reflect the stream velocity in the catchment, and Sa, the sand topsoil content. It is paraxodal that runoff increases with sand content, but this can be explained by the higher susceptibility of sandy soils to crusting than more resistant well aggregated clayey soils (Valentin and Bresson, 1992).

The best correlations were established for the runoff coefficient and for the bedload, data easier to collect and assess than the suspended load and therefore the sediment yield. Our data clearly demonstrate that annual crops, especially maize and cassava, without conservation practices, promote soil erosion at the catchment scale. Annual crops in upland catchment have therefore an off-site impact on water quality. These data are consistent with those obtained on field plots. They infirm the doubts about the role of upland agricultural activities in generating runoff and sediments at the catchment level. Similarly, they epitomize the positive role of conservation technologies in reducing runoff and suspended load. In other words, they contradict the emerging revisionist mood (Tomich et al., 2004).

Among the annual crops, maize, especially cultivated up and down twice a year, and cassava are the most erosive. This is due to rather low vegetative cover and the need for repeated weeded operations. Cassava often replaces the main staple crop (upland rice) because it is less demanding. The recent development of maize in Southeast Asia is associated with rising prices and improved market access (Cramb, 2005.). It might be also due to a response to shorter summer monsoon. Current observations (de Rouw et al., 2005) also suggest that the conversion of upland rice (C3-plant) to maize (C4-plant) is associated with similar changes in weeds, the native forest vegetation tending to be replaced by a savannah-type vegetation.

In Vietnam sediment yields have been greatly reduced after the replacement of cassava by tree plantations and fodder crop. Conversely, soil erosion has increased in Laos due to the shortening of the fallow period and the recent cultivation of maize. More often, farmers tend to encroach on tree plantations or to destroy them to extend annual crops, as exemplified in Indonesia and Philippines.

Despite their efficiency in combating soil erosion, only few conservation techniques are adopted on the long term by farmers. Planting grass on the bench terrace risers and in the lower areas of the catchments in Indonesia was adopted by a majority of farmers. Although present in most catchments, the proportion of forest or tree plantations did not appear as a key factor for soil conservation. The advantages of the mostly spontaneously adopted agro-forestry systems are best illustrated in Indonesia while these systems are not well accepted by farmers of other countries. Tree plantations on the hill-slopes, which greatly limit soil erosion, are blamed by farmers to deplete water availability of downstream irrigated rice in Vietnam. Despite their effectiveness in combating erosion, natural vegetative strips introduced in the Philippines site was adopted only by the landowners, but no tenant farmers, due to cost of establishment. Fodder crop appears as an interesting alternative only for farmers who have sufficient land to grow arable crops. It must not be overlooked that conversion from field crops to fodder/livestock often occurs when the quality of the land had degraded so much that cropping is no longer worthwhile.

As shown in Fig. 2, soil erosion tends to increase with population density. Yet, the Indonesian catchment clearly illustrates that very dense population can control soil erosion, using terrace and organic amendment.

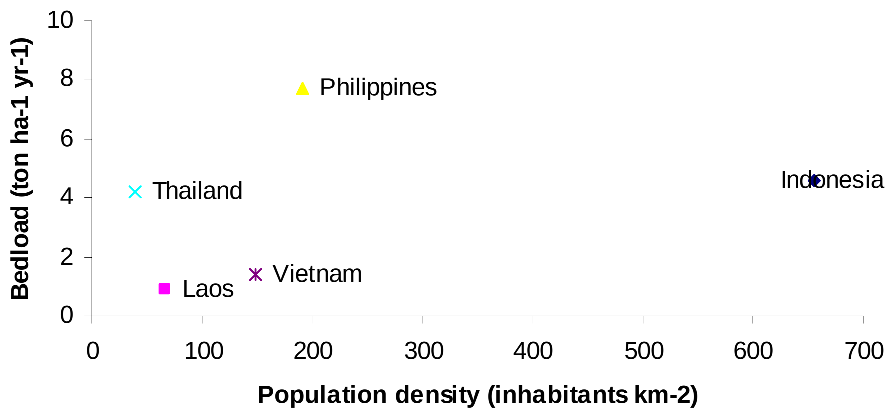

Fig. 2. Mean bedload from the catchments and population density.

These five cases also suggest that soil degradation is not invariably associated with poverty since soil erosion tends to increase with income per capita (Fig. 3). The relatively low soil erosion rate in Thailand is not due to investment by farmers in soil conservation technologies but rather to the fact that the soils have been so eroded by farming that a surface gravel layer protects the soil from further erosion.

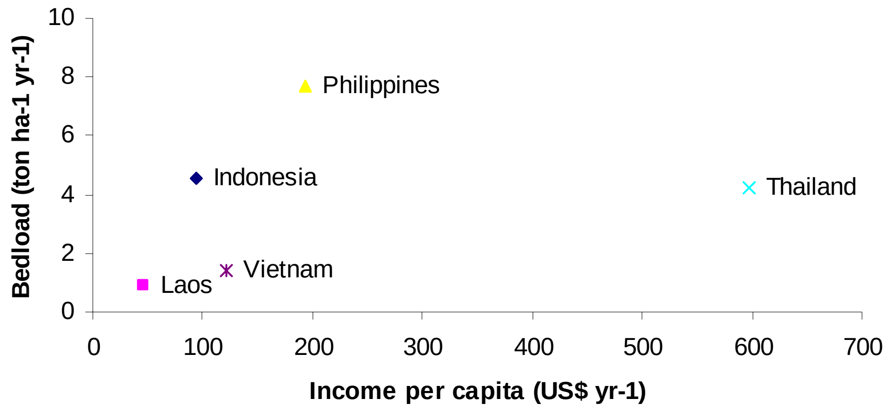

Fig.3. Mean bedload from the catchments and income per capita.

5. Conclusion

Based on the data from 27 catchments of Southeast Asia monitored during 3-5 years, this study showed that:

- It is essential to conduct long term studies at the catchment scales (i) to capture land use changes under real world conditions and their impacts on runoff and erosion, (ii) to test new technologies and their effects in mitigating possible off-site impacts, (iii) to increase chance to record an exceptional event, (iv) to analyse various processes, their possible time lag responses to land use change and their cumulative effects. In this respect, an international network of long term monitoring sites can be considered as an invaluable tool not only for scientists but also for policy makers.
- Runoff and soil erosion are predominantly influenced by land use not only at the plot scale but also at the catchment scale.
- The conversion of upland rice or orchards to maize and cassava greatly increases. runoff and sediment yields and the catchment scale. Maize and cassava are major predictors for bedload erosion.
- The conservation technologies ((improved fallow, direct sowing, grass strips and natural vegetative strips, terraces with grass risers) are efficient not only at the plot scale but also at the cachment scale.
- To be adopted by the farmers, conservation strategies need to be tailored to the local demographic, economic and cultural conditions. This diversity needs to be more acknowledged by international agencies and donors, some of them being too specialized in a single strategy.

- Land degradation is not invariably associated with poverty and high population density. Under high density conditions, farmers are more incline to adopt and maintain more sustainable practices. The farmers with highest income are reluctant to invest in conservation technologies.
- If no incentives reward upland communities that adopt appropriate land use management systems, it is most likely that land degradation will increase in the next few decades with off-site consequences for more urban and industrialized lowland communities.

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